Short-Baseline neutrino oscillation searches with the ICARUS detector

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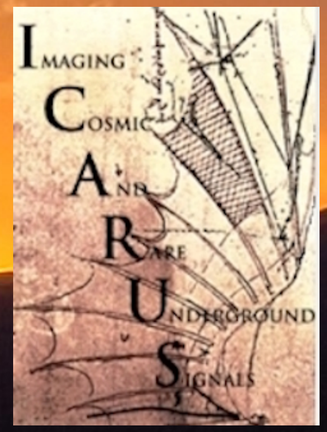
for the ICARUS Collaboration



NuFACT 2022
August 02, 2022

ICARUS : Imaging Cosmic And Rare Underground Signals

- First large LArTPC: still one of the largest in operation
- Two cryostat: each 19.6 x 3.6 x 3.9 m^3
  760t total LAr mass / 476t active
- Two TPCs per cryostat, with a common central cathode:
  1.5 m drift length, E_{Drift}= 500V/cm, V_{Drift}~1.6 mm/μs,
  3 mm wire pitch
- Three readout wire planes per TPC, ≈54000 wires at
  0°, ±60° w.r.t. horizontal
- Ionization charge continuously read (400 ns sampling time) by three readout wire planes per TPC
- Each TPC has 90 8" PMTs, 15 phe/MeV deposited energy
- ~4π coverage of Cosmic Ray Tagger (CRT)

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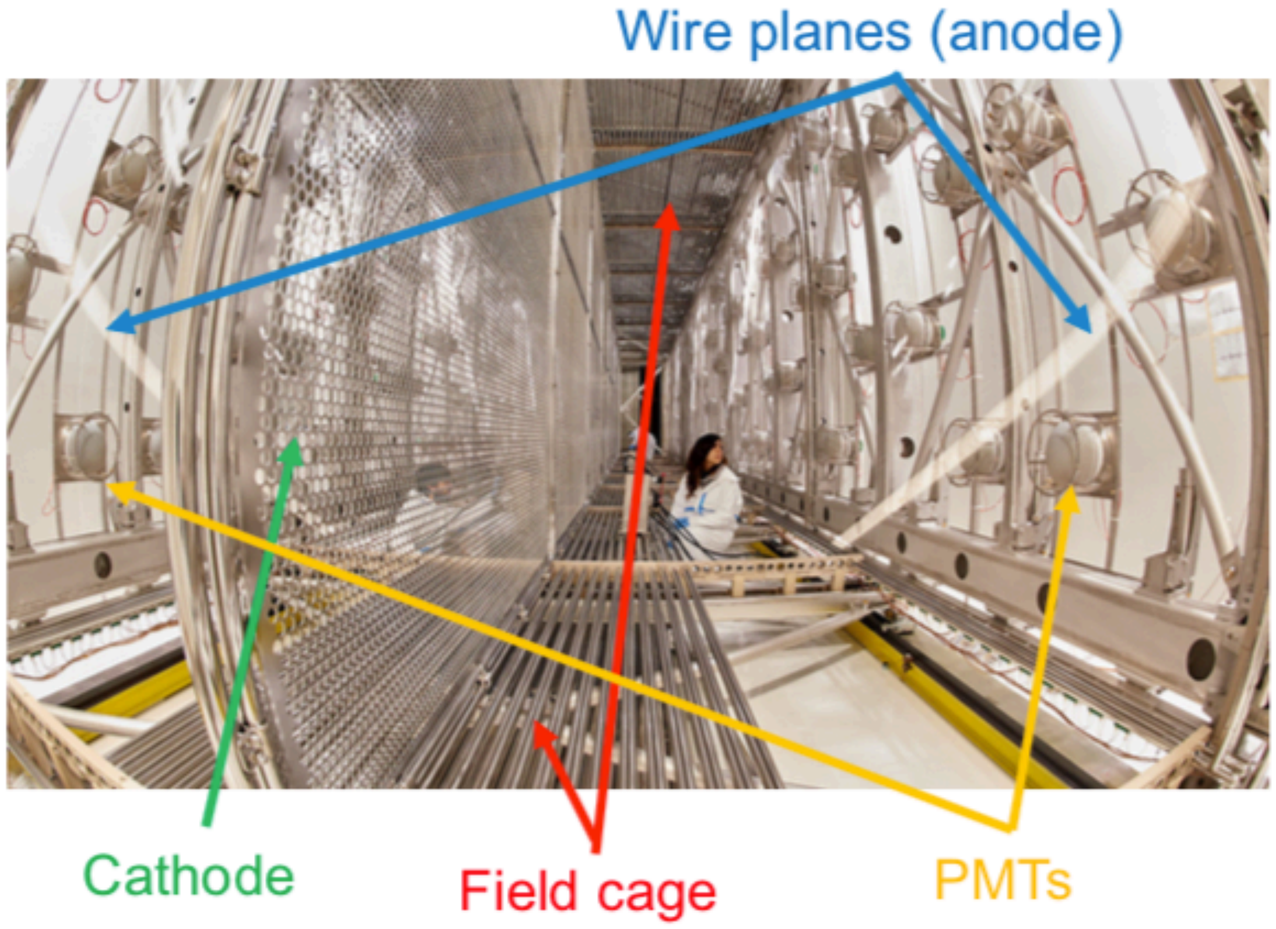
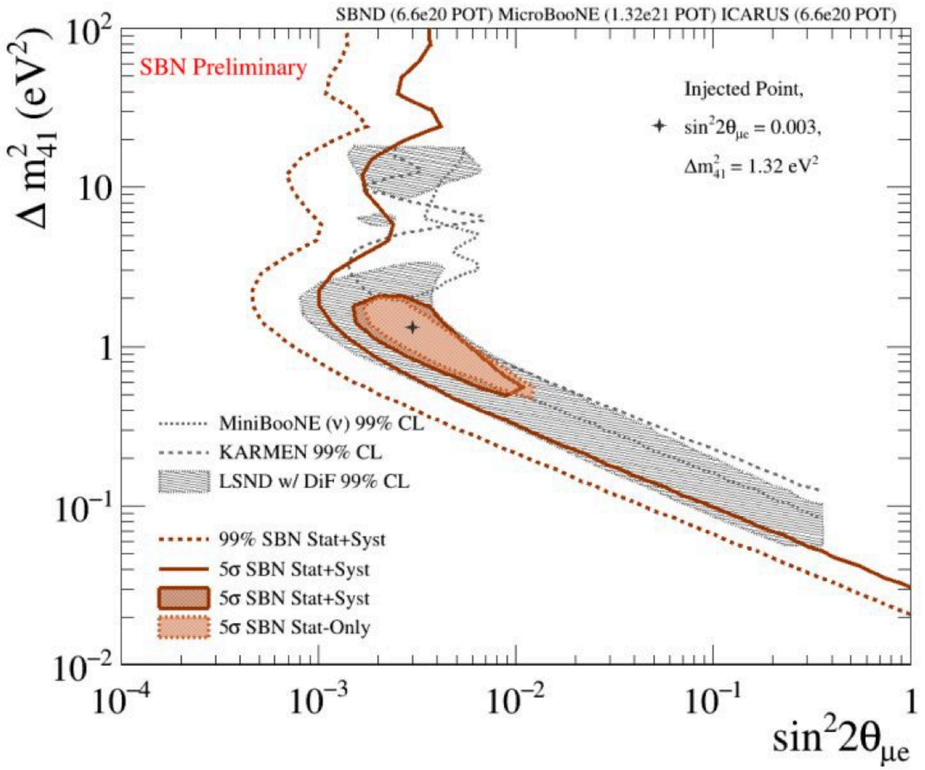


SBN expected sensitivities

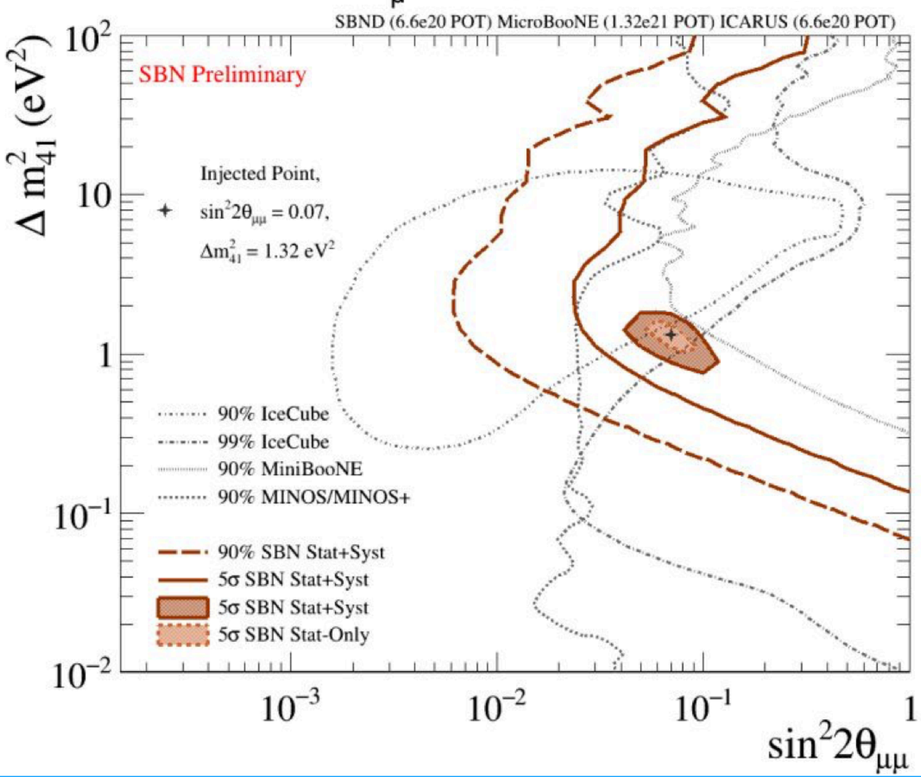
Please follow a talk by
Mark Ross-Lonergan on Thursday 9.30 AM

The combined analysis of near and far detector data will allow to cover the currently allowed parameter region with 5**σ** sensitivity both in appearance and disappearance channels in 3 years of data taking

SBN ν_e **appearance only**



SBN ν_μ **disappearance only**

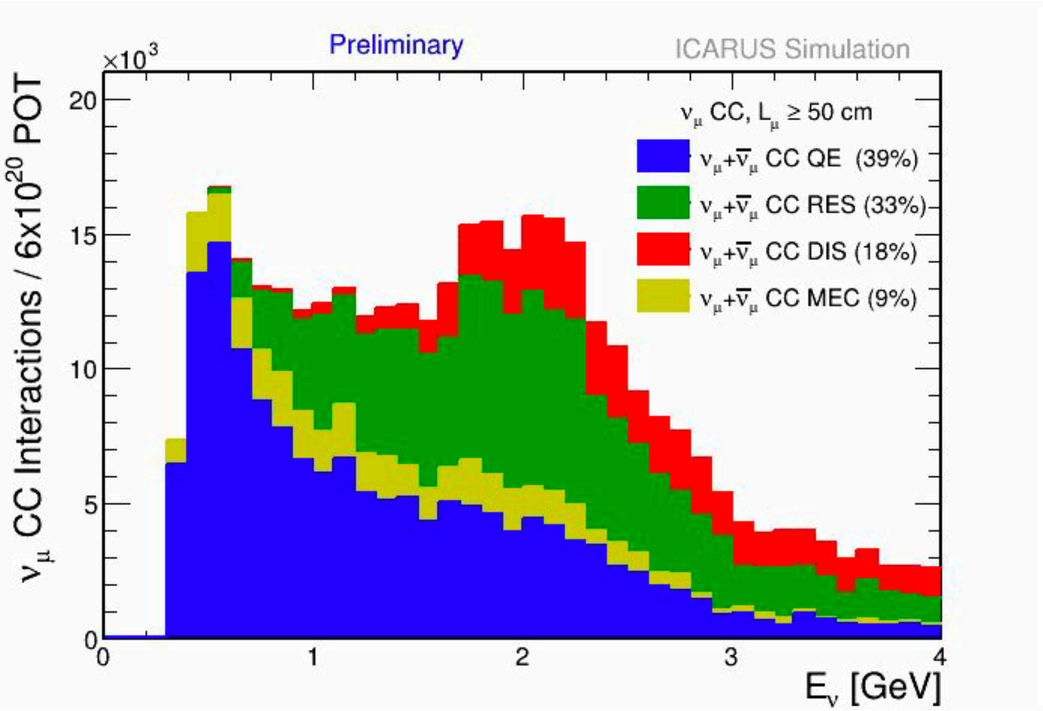


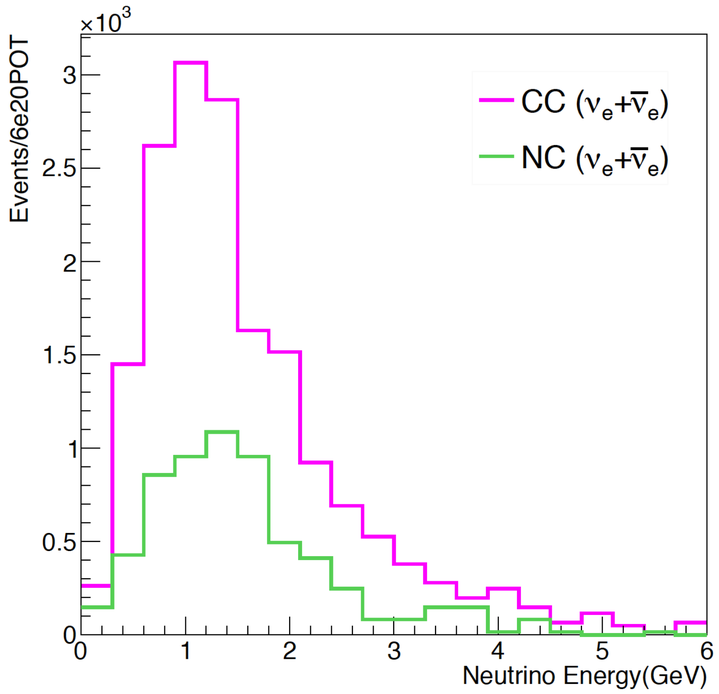
Systematic errors will reduce using the same detector technology. Near detector helps in providing the initial beam composition and the spectrum. The clear electron neutrino identification capability will help on reducing backgrounds

Physics searches with NuMI

High statistics precision measurements of neutrino argon cross sections and tests of interaction models in the few hundred MeV to few GeV range, of use to SBN oscillation studies and DUNE.
~ 10^5 electron neutrino events/year.

Rich BSM searches: Higgs portal scalar, neutrino tridents, light dark matter, heavy neutral leptons…



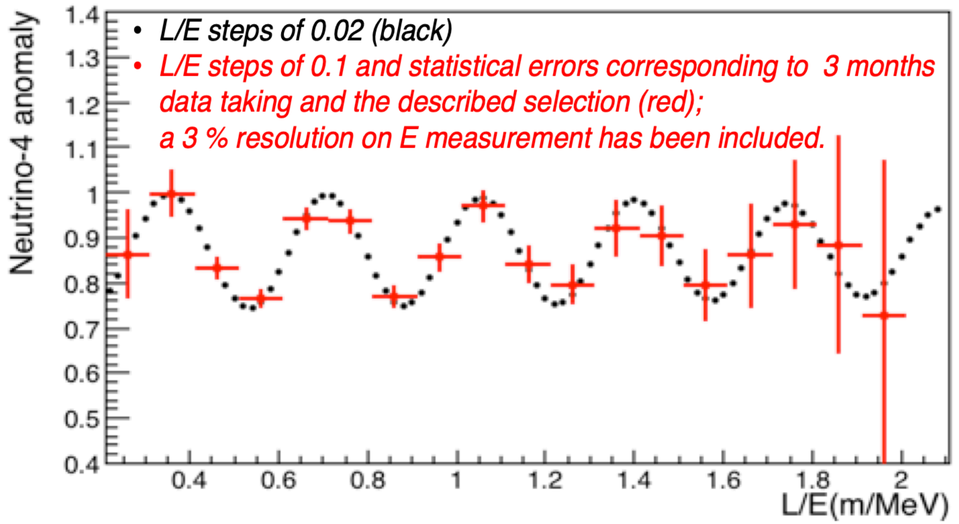


Please follow a talk by Minerba Betancourt on Thursday 4.30 PM

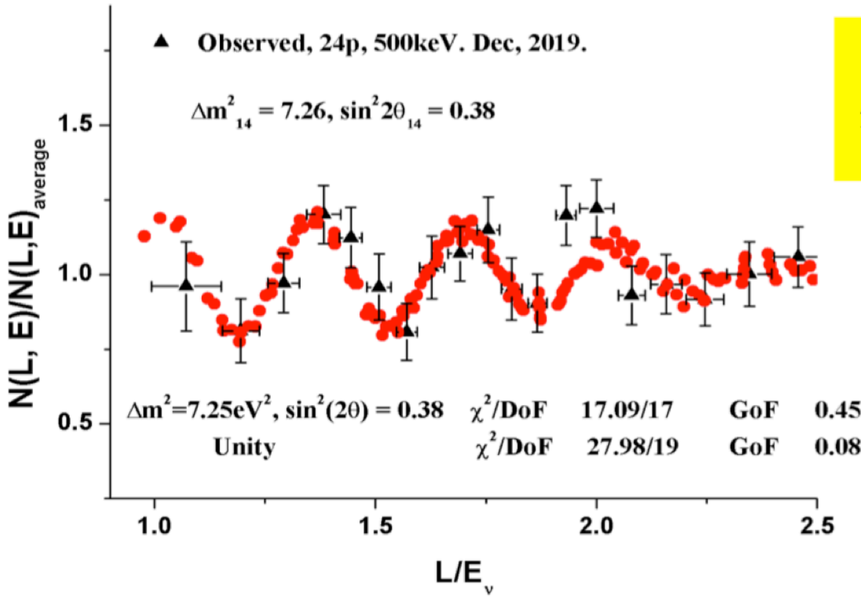
Search for Neutrino-4 oscillation signal

The Neutrino-4 collaboration claimed a reactor neutrino disappearance signal with a clear modulation with L/E ~ 1-3 m/MeV.

ICARUS will be able to test this oscillation hypothesis in the same L/E range in two independent channels, with different beams



NEUTRINO-4 reactor signals



The period of oscillation for neutrino energy 4 MeV is 1.4 m

A.P.Serebrov, et al.
JETP Letters,
Volume 109,
Issue 4, pp 213–221.

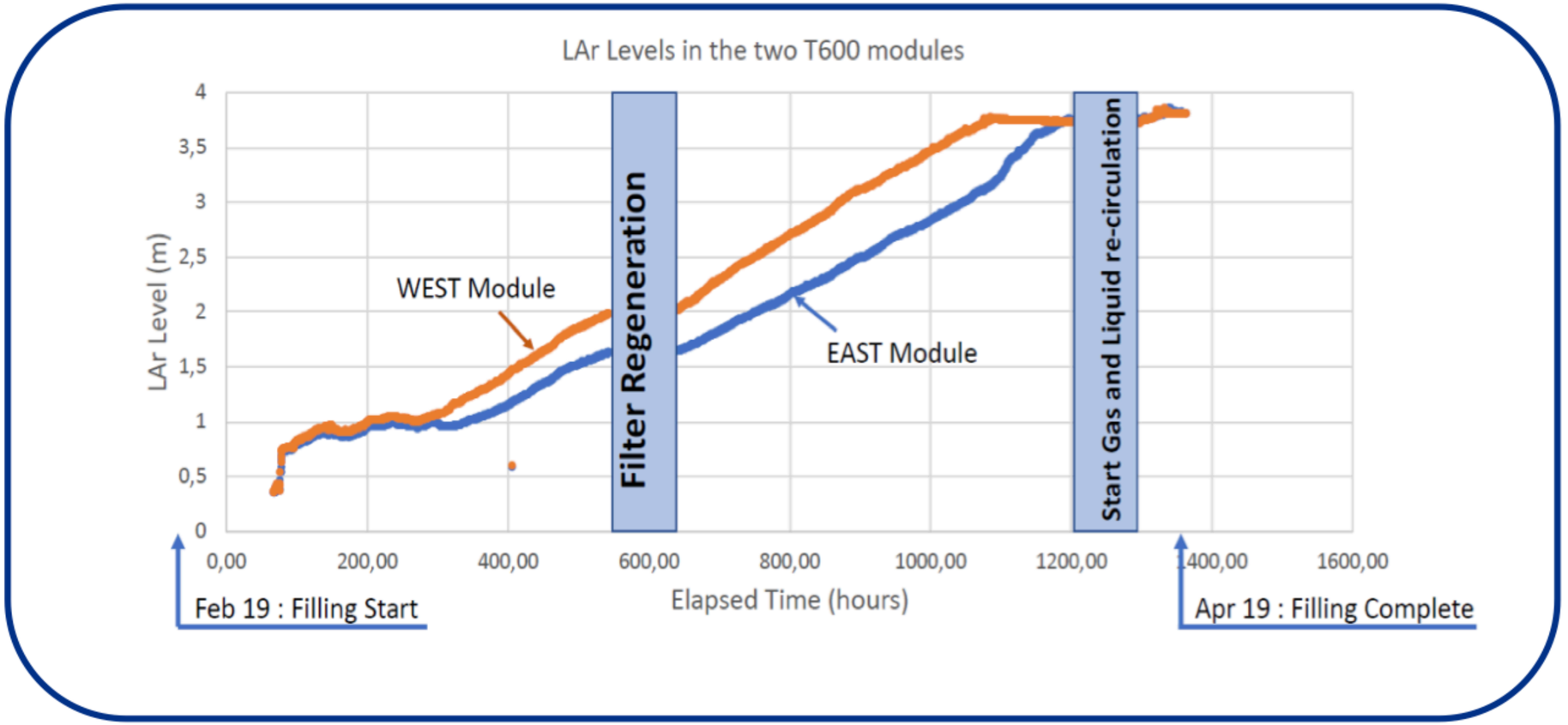
arxiv:1809.10561

Disappearance of muon neutrino from the BNB beam, focusing the analysis on Quasi-elastic contained charge current muon neutrino interactions where the muons is at least 50 cm long. ~ 11500 events are expected in 3 months of data taking

Disappearance of electron neutrino from the NuMI beam, selecting contained EM shower from quasi-elastic charge current electron neutrino interactions. ~ 5200 events are expected in a year

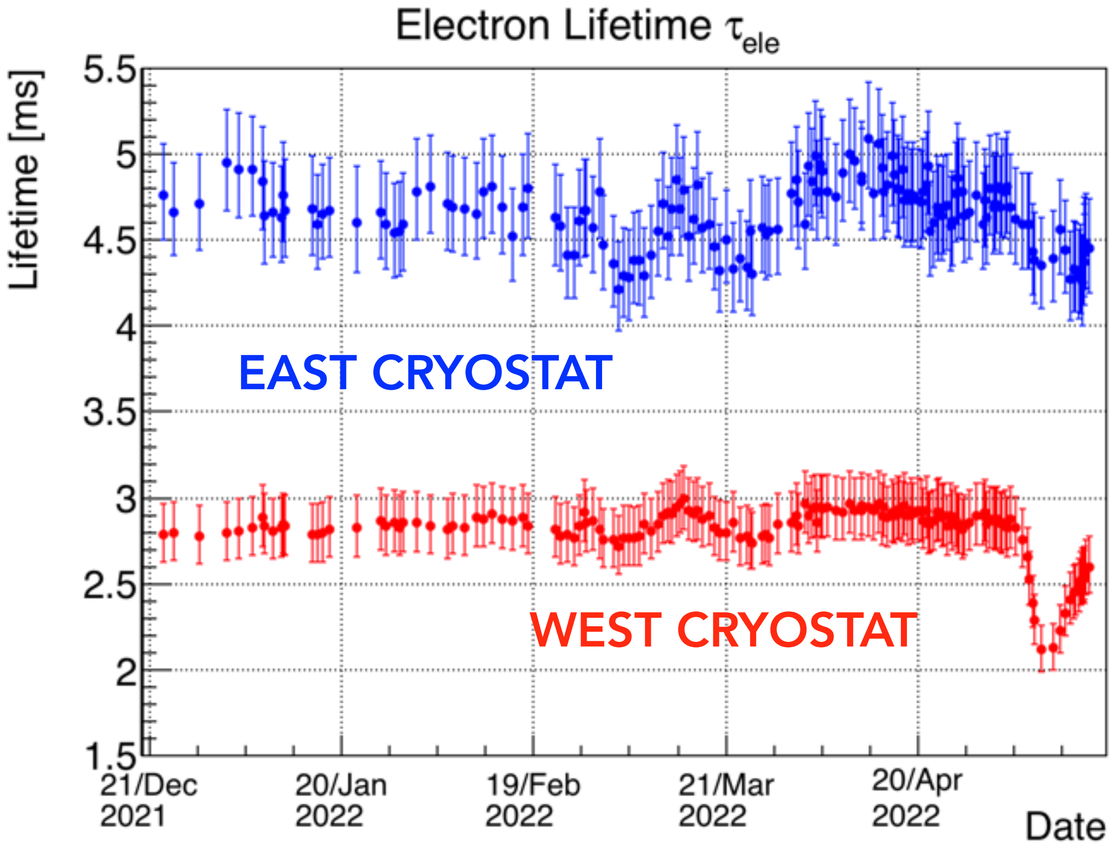
Activation and Commissioning

After installation, ICARUS began cooldown and filling Feb 2020. By Fall 2020 detector was activated to the full electric drift field of -75kV (500 V/cm) was reached.



All the TPC readout electronics, PMTs, CRTs and Overburden has been installed and commissioned by June 7, 2022.

Electron Lifetime Measurement

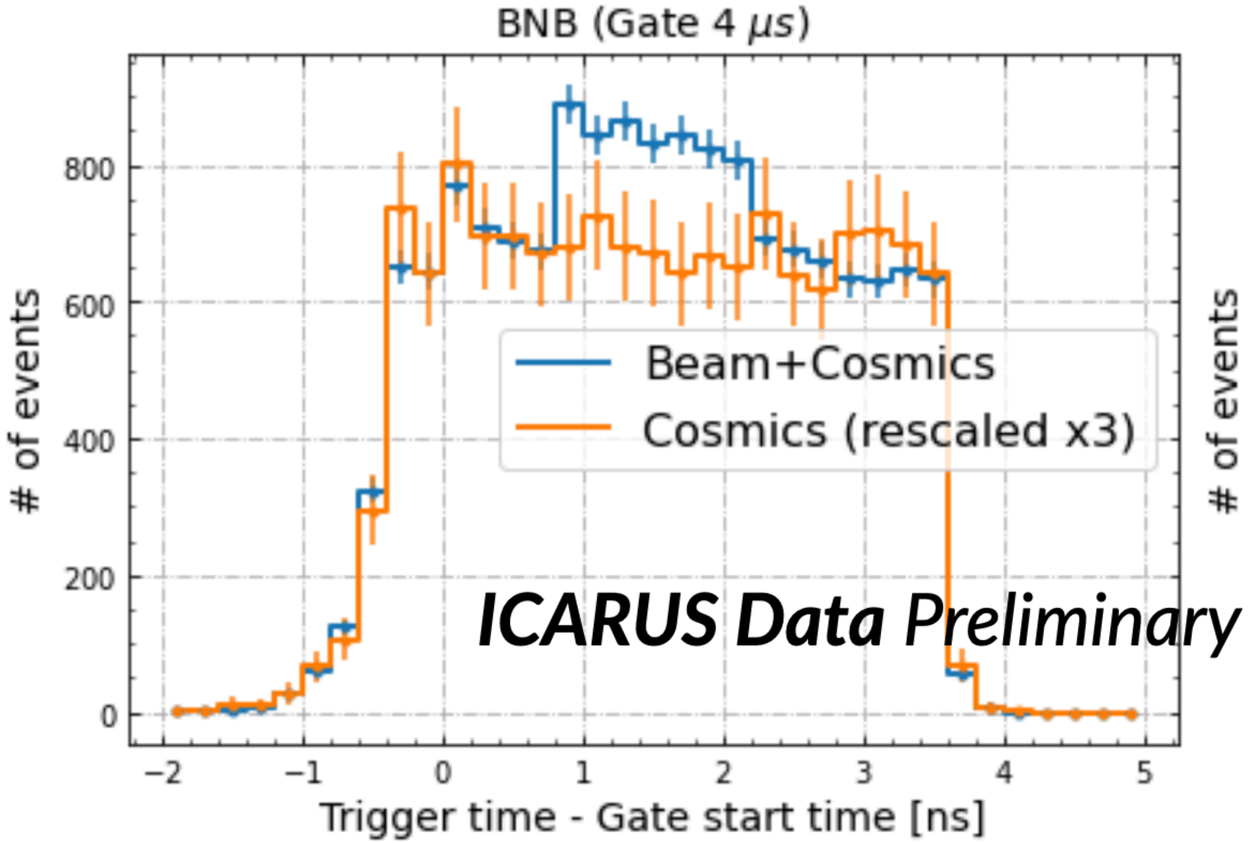


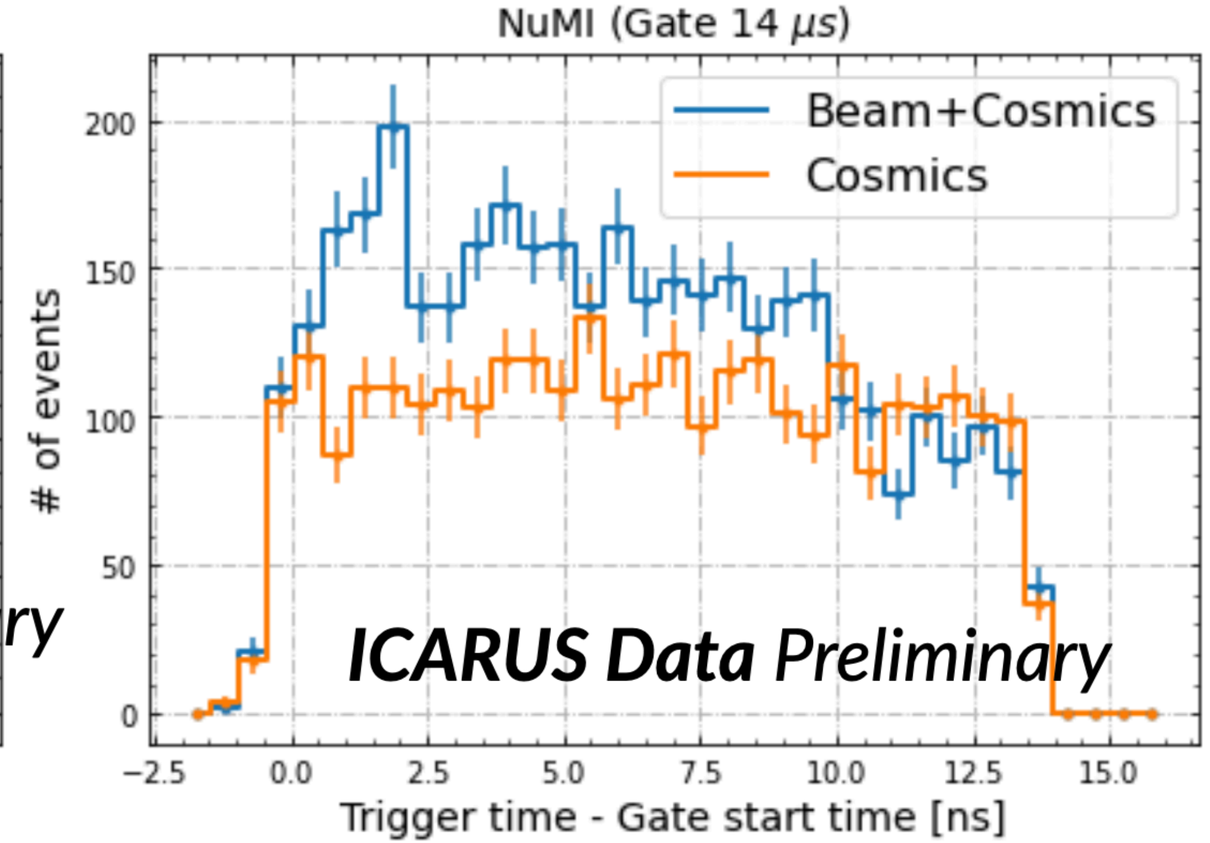
Please follow a talk by Gray Putnam on Calibration [Friday 3:32 PM]

The liquid argon purity level is continuously monitored by measuring the signal attenuation along the drift direction along crossing cosmic muon tracks: the electron lifetime reaches up to ~4.5 ms in the East Cryostat and ~3 ms in West, allowing efficient signal detection over the full LAr volume.

Trigger System

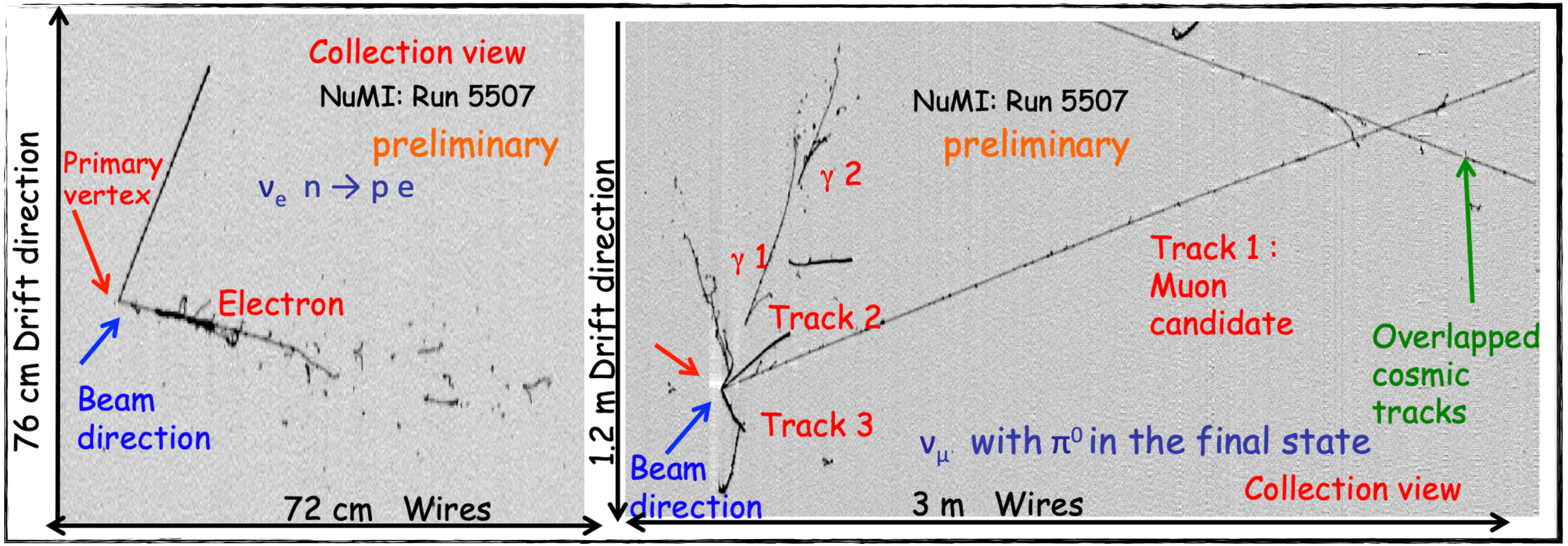
Main ICARUS trigger signal generated by majority of the discriminated pairs of PMT signals in coincidence with the BNB and NuMI beam spill gates, 1.6 and 9.5 μs respectively.





Neutrino Candidate from NuMI Beam

Electromagnetic shower with E_{dep} ~ 600 MeV, upward-going hadron (proton or pion candidate) with length ~ 43 cm

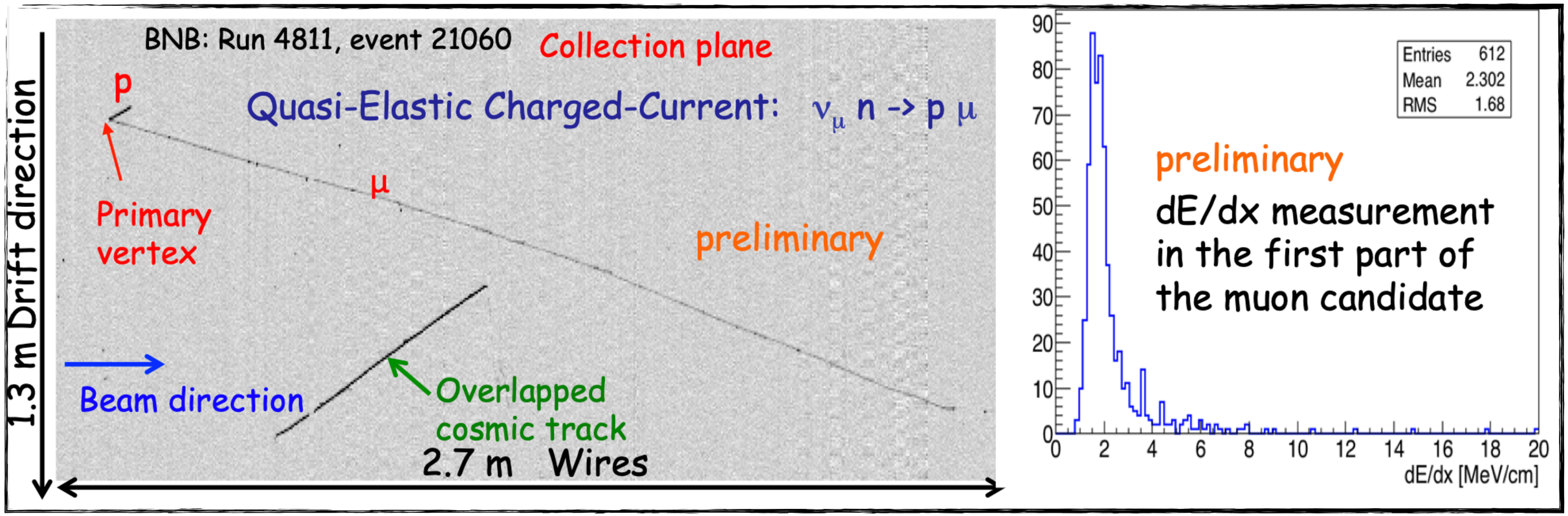


Track 1: muon candidate crossing the cathode and exiting downstream (L~4.2m, p~1.3 GeV/c from MCS)

Track 2: upward-going proton candidate, L~31 cm.

γ1,γ2: photons of 200 and 240 MeV respectively, converting at 18 and 58 cm from neutrino interaction vertex. Possible π_0 candidate

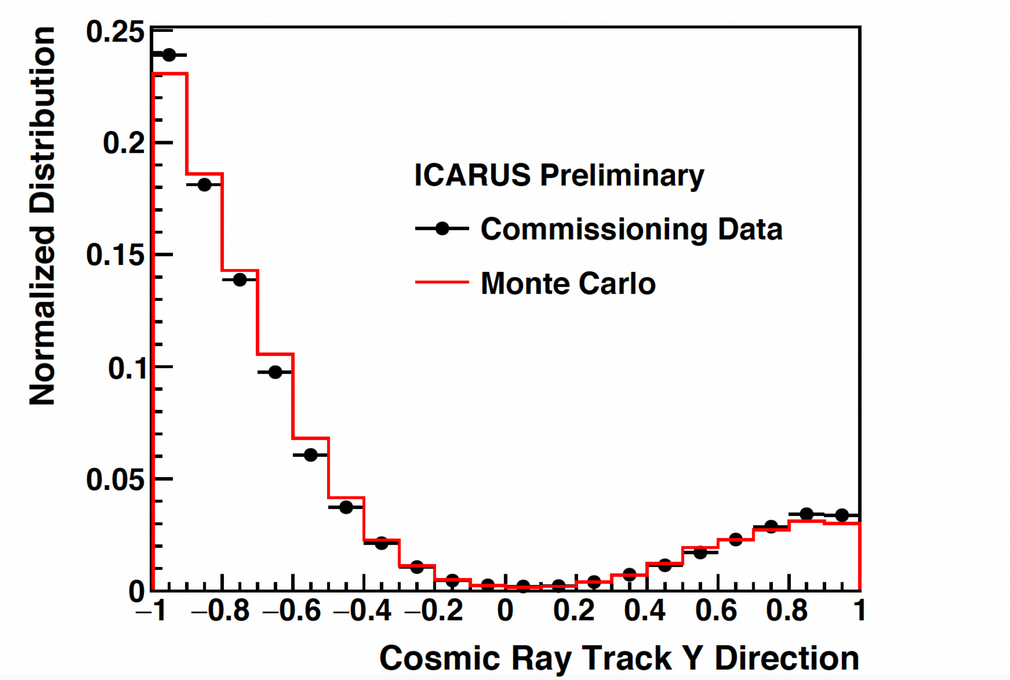
Neutrino Candidate from BNB Beam

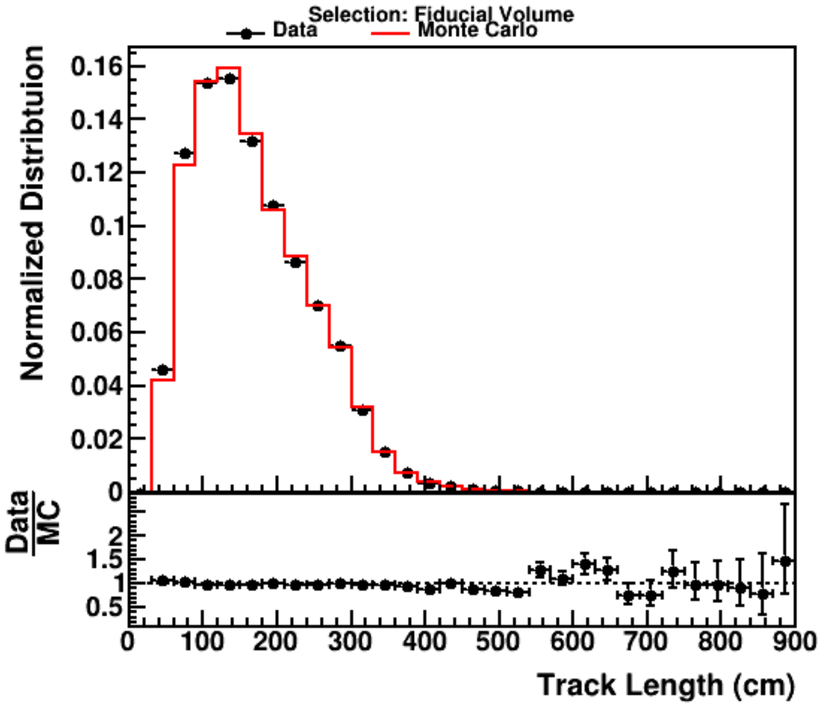


Two tracks produced at the primary vertex, both stopping (left picture): the muon candidate is stopping after = 2.8 m with E_{dep} ~ 650 MeV while the proton candidate is stopping after 10.9 cm with E_{dep} ~ 100 MeV

Track reconstruction: data/MC comparison

Comparison of cosmic events reconstructed in data and MC. Several reconstructed quantities have been studied to understand the features of the reconstruction.





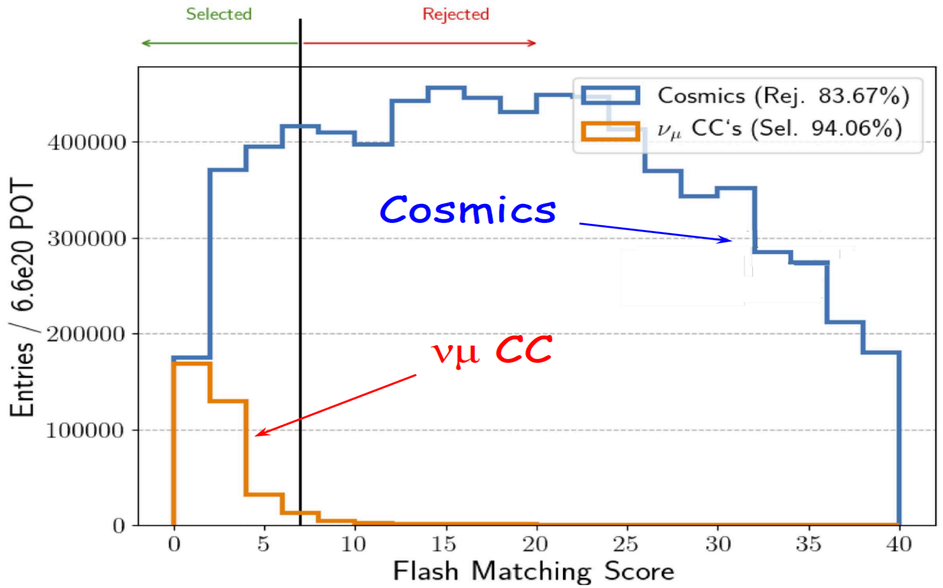
Preliminary indications of good end to end processing chain for both data and simulation.

PMT light signal – TPC event association

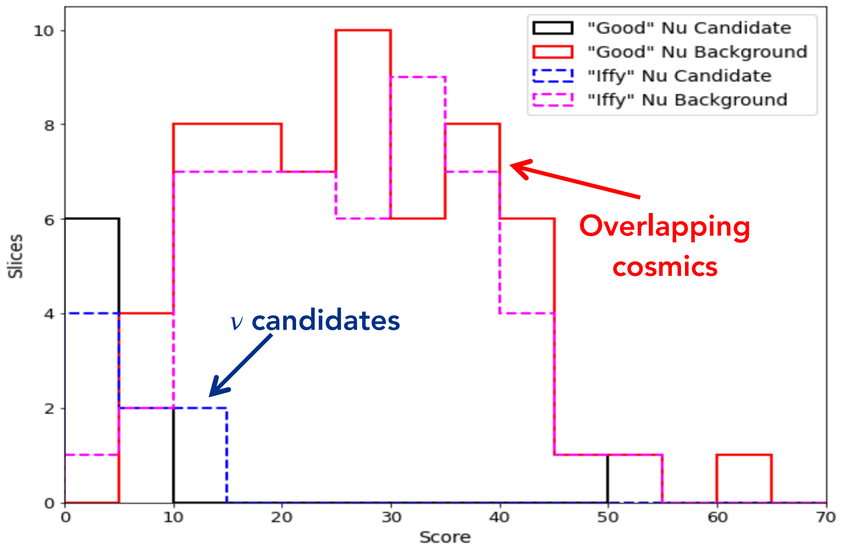
The agreement between the light signals of PMTs firing in coincidence in 100 ns (“flash”) and the reconstructed TPC event is quantified by a “flash score” based on

- weighted barycenter of light signals and barycenter of deposited TPC charge;
- dispersion of fired PMTs around the light barycenter;
- sharing of the total detected light between the two PMT walls in each cryostat.

MC BNB ν_μCC interactions and random cosmic overlays



Flash matching in Data



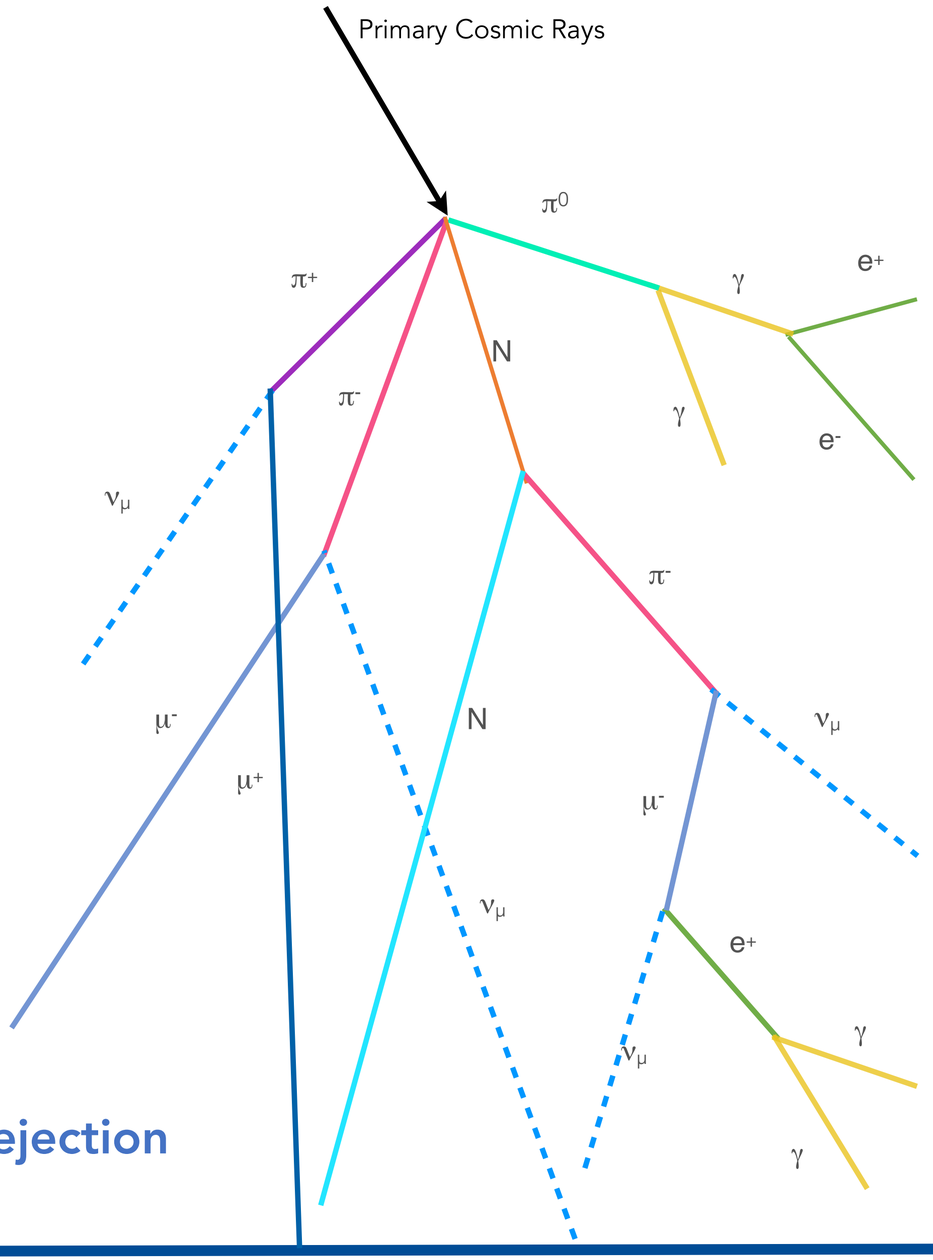
The score is small (large) for correlated (uncorrelated) PMT and TPC reconstructed events, as determined in MC and verified in collected data.

Cosmogenic Particle

- ICARUS is on the surface and exposed to huge cosmic activity, is the primary background for several physics analysis.

- The electromagnetic showers generated by cosmic particles crossing the detector in time with the beam spill have to be reduced as much as possible a priori since they may introduce a background for the ν_e CC analysis.

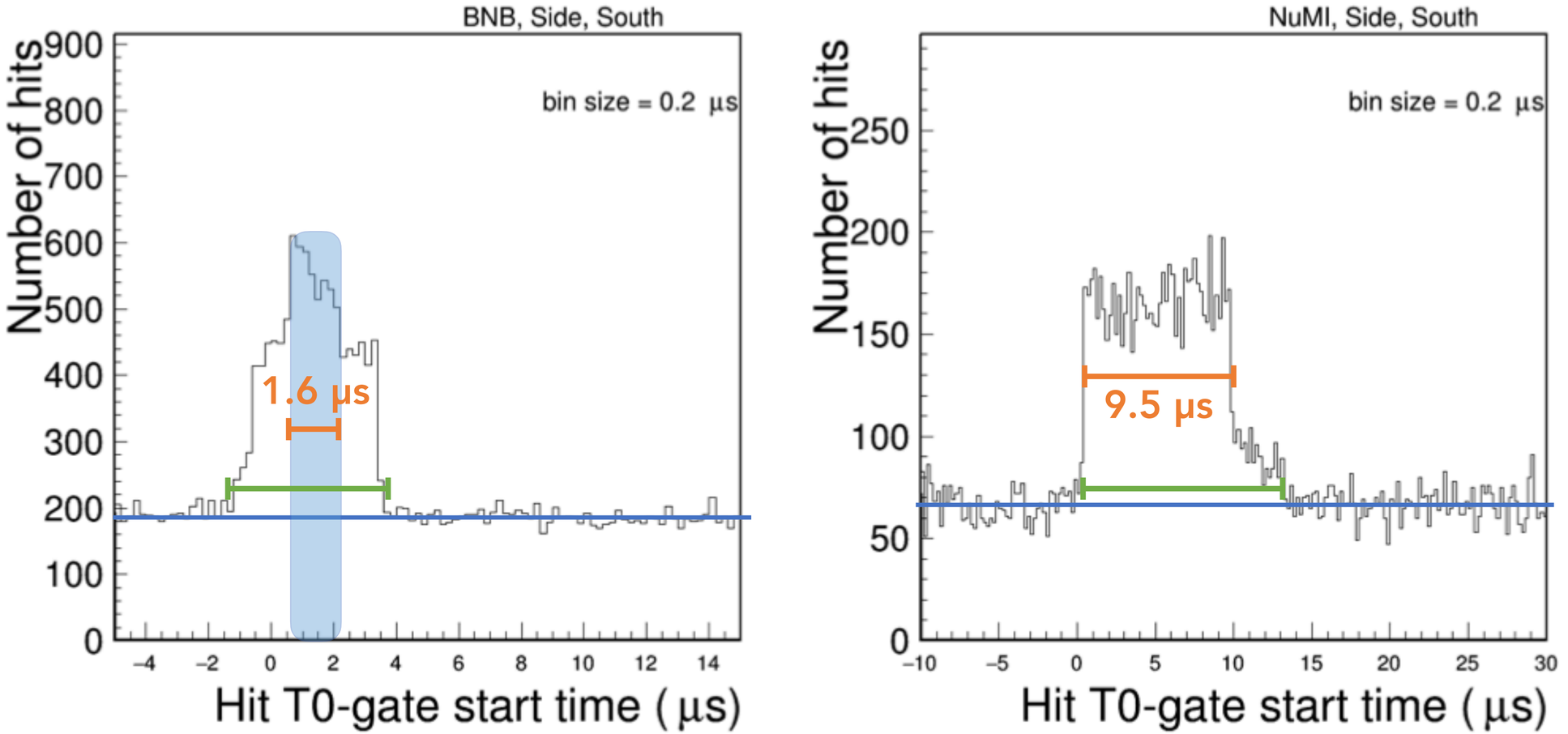
- In the approved Fermilab SBN[1] experiment the impact of cosmic rays is mitigated by placing ~ 3 m concrete overburden placed on top of the ICARUS detector and ~4π coverage of Cosmic Ray Tagger (CRT) were introduced.



Please follow a talk by
Biswaranjan Behera on Cosmic Rejection
Friday, 4.39 PM

1 arxiv: 1503.01520

CRT Reconstruction



- Coincidence windows were extended to 4 μs (BNB) and 12 μs (NuMI)
- More activity in those 4 μs (trigger bias), and even more so when there is additional activity from the beam (1.6 μs within the 4 μs) and other than 1.6 μs are from cosmic triggering

Summary and Outlook

- The commissioning phase of ICARUS-T600 has largely been successful, despite the inconveniences due to the current pandemic.
- The initial deployment of the trigger system allowed to observe the first neutrino events from both BNB and NuMI beams.
- Collected neutrino events are being used to further develop and tune the event filter and the reconstruction software.
- The CRT and Overburden completely installed and commissioning has been completed on June 2022.
- Collecting physics data with both BNB and NuMI beams starting its searches for new Physics Beyond the Standard Model

Thank you for your attention!

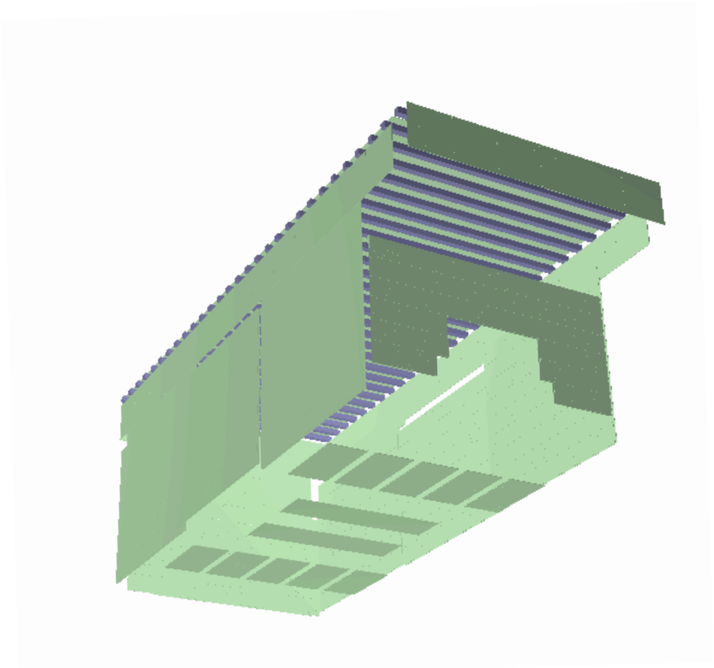
Back up

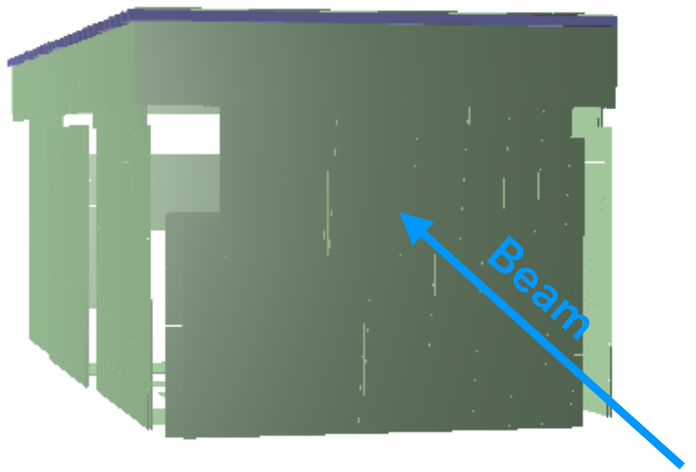
Cosmic Ray Tagger (CRT)

CRT system detects charge particles entering the detector from outside, whose tracks may interfere with the reconstruction of beam neutrino events

CRT system surrounds the exterior of the warm vessel as much as reasonably possible

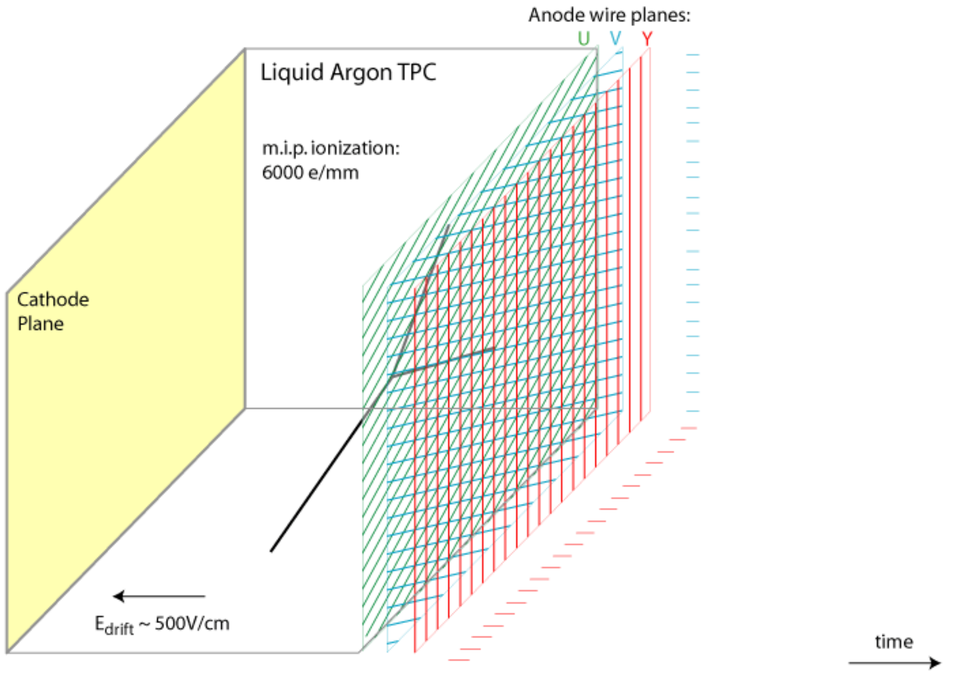
It has three sub-systems with different modules and different readout electronics





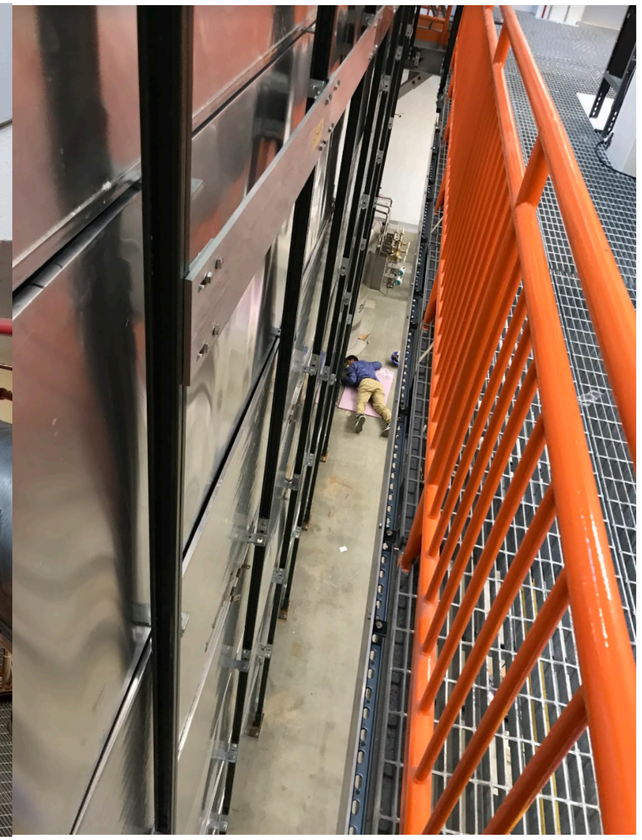
Liquid Argon Time Projection Chamber (LArTPC)

- **Low Thresholds :** important for detecting low-energy particles (e.g. protons from hadronic part of neutrino interactions)
- **Excellent Calorimetry :** important for precise estimation of neutrino energy, particle ID with dE/dx
- **High Spatial Resolution :** allows for background rejection and particle ID
- **Scalability :** large detectors yielding high event rates for precision physics



Installation and Commissioning of CRT



Light Collection System

High time resolution ~ ns, Measured dark count is < 5kHz, QE ~12% and stable gain is 10^7 @87K to detect single photoelectron. Gain calibration in cryogenic environment performed with laser

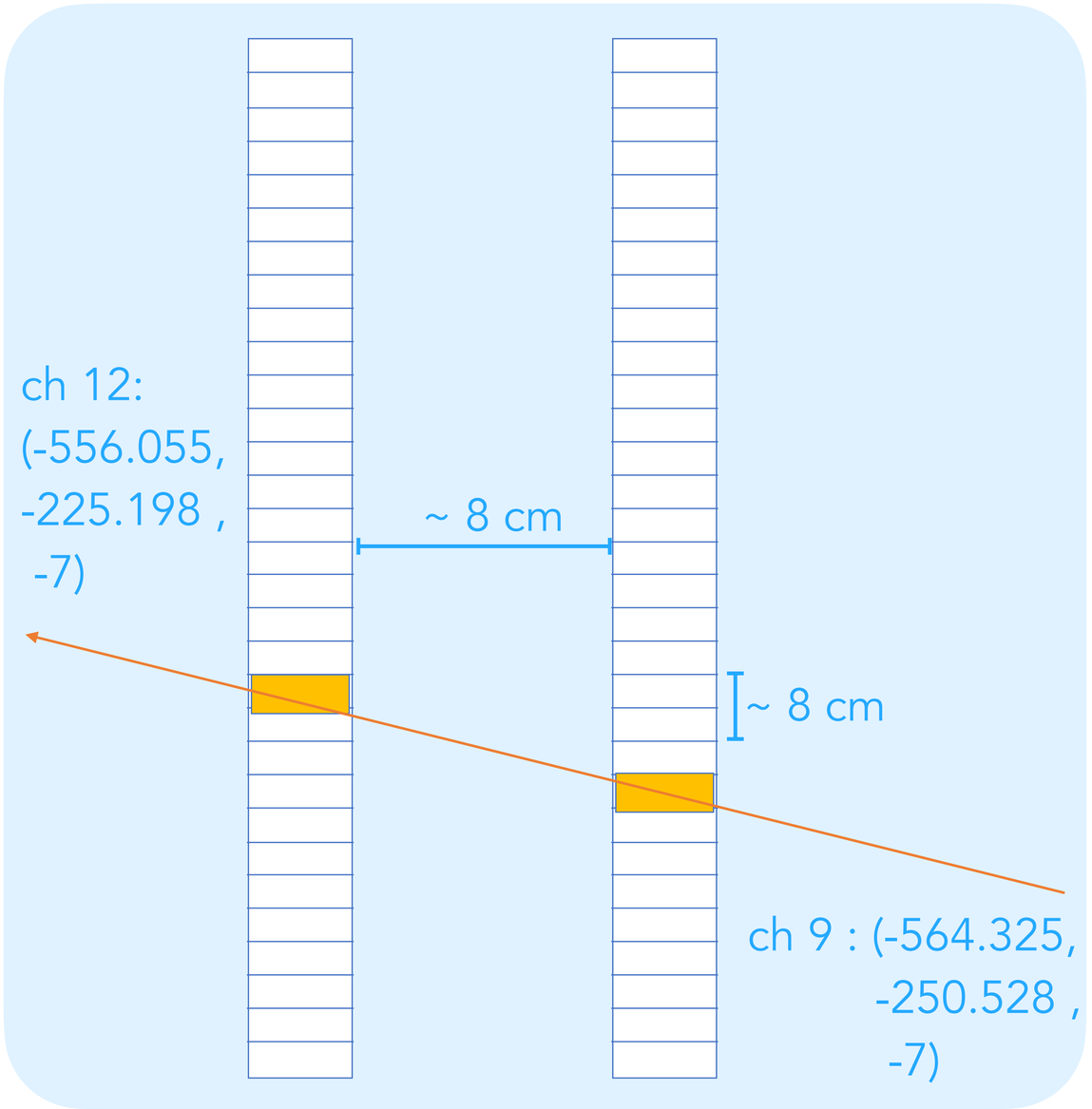
Each TPC has 90 8" PMTs installed behind wire plane (5% photo cathode coverage, 15 phe/MeV deposited energy is collected)

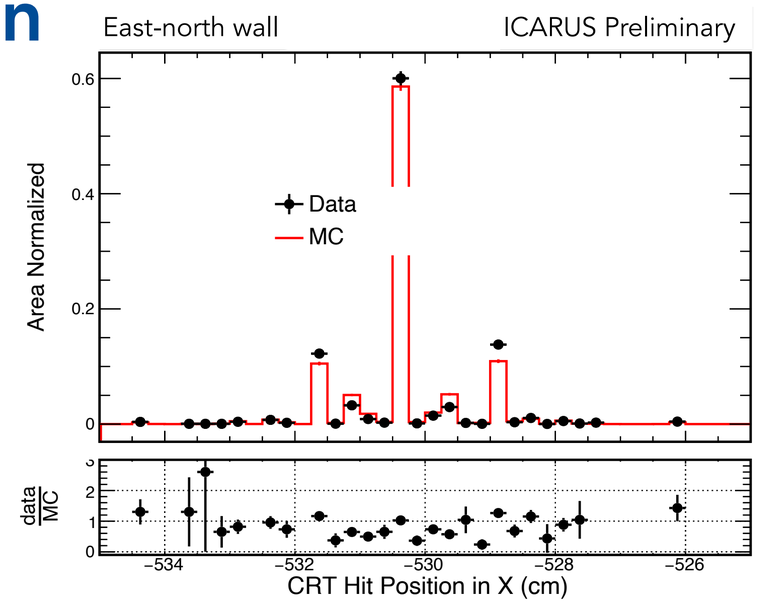
Generate a trigger signal for read-out, sensitivity to low energy events (~100 MeV)

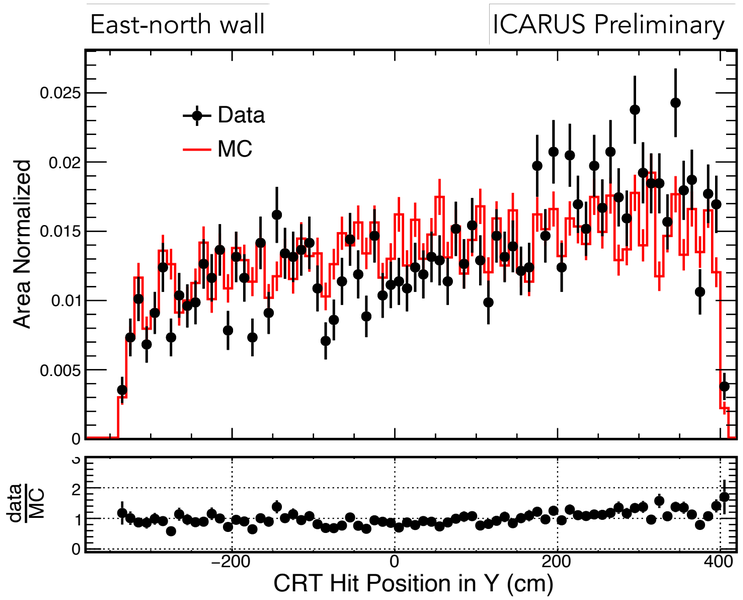
High spatial granularity, longitudinal resolution better than 50 cm

Identify cosmic muons by PMT space/time pattern

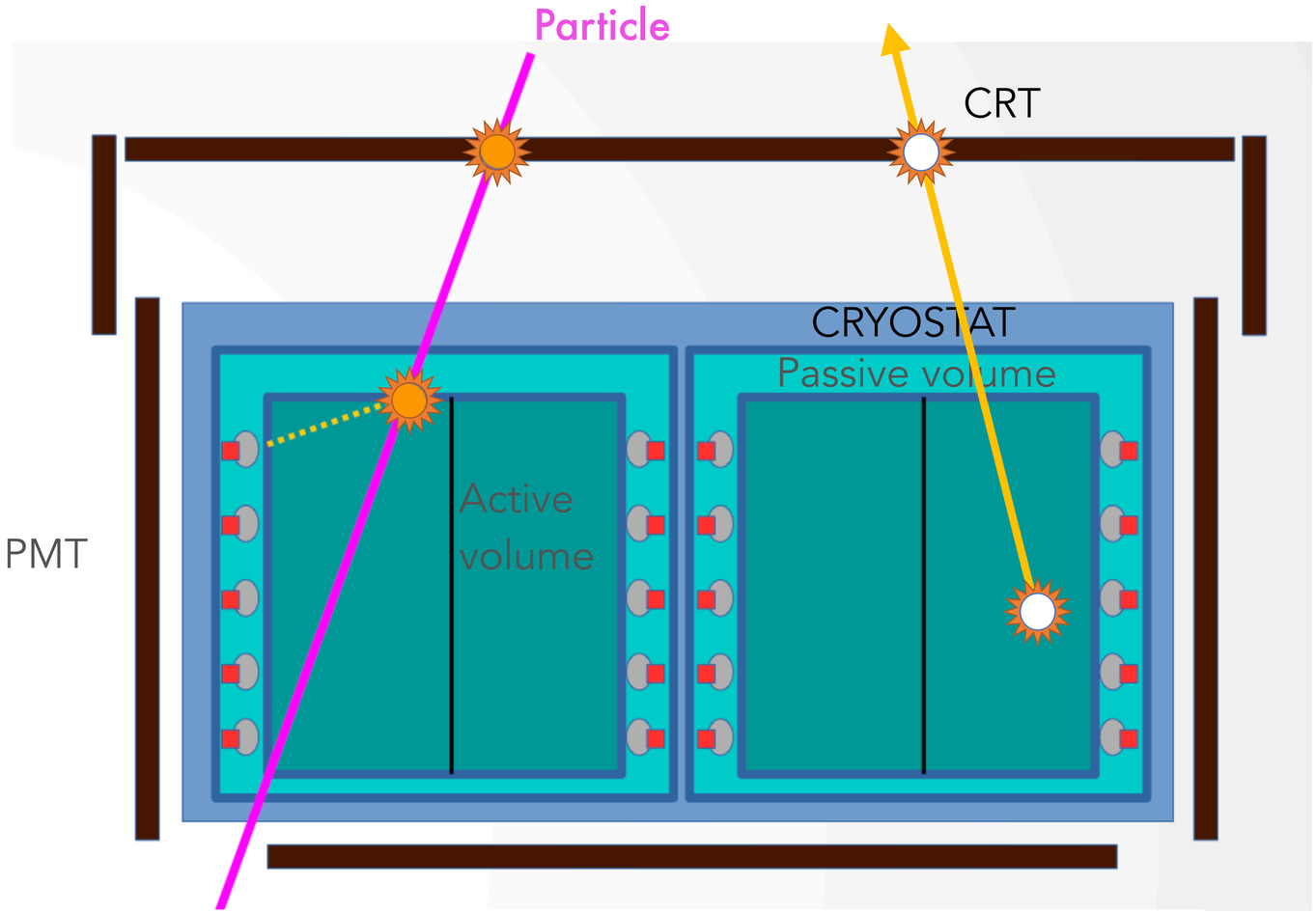
CRT Hit Reconstruction Data/MC comparison







CRT - PMT Time of Flight



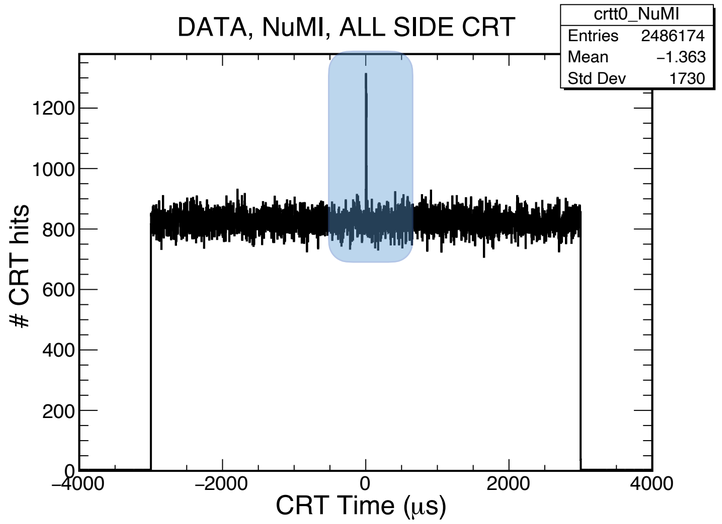
We can discriminate in-going cosmic tracks and from exiting neutrino tracks using the time of the CRT and PMT information

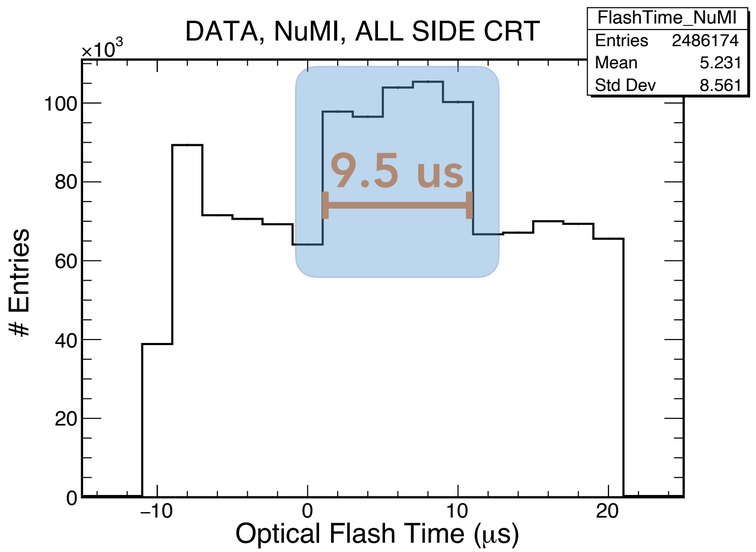
$T_{CRT} - T_{PMT} > 0$ (tracks generated by neutrino that leave the detector)

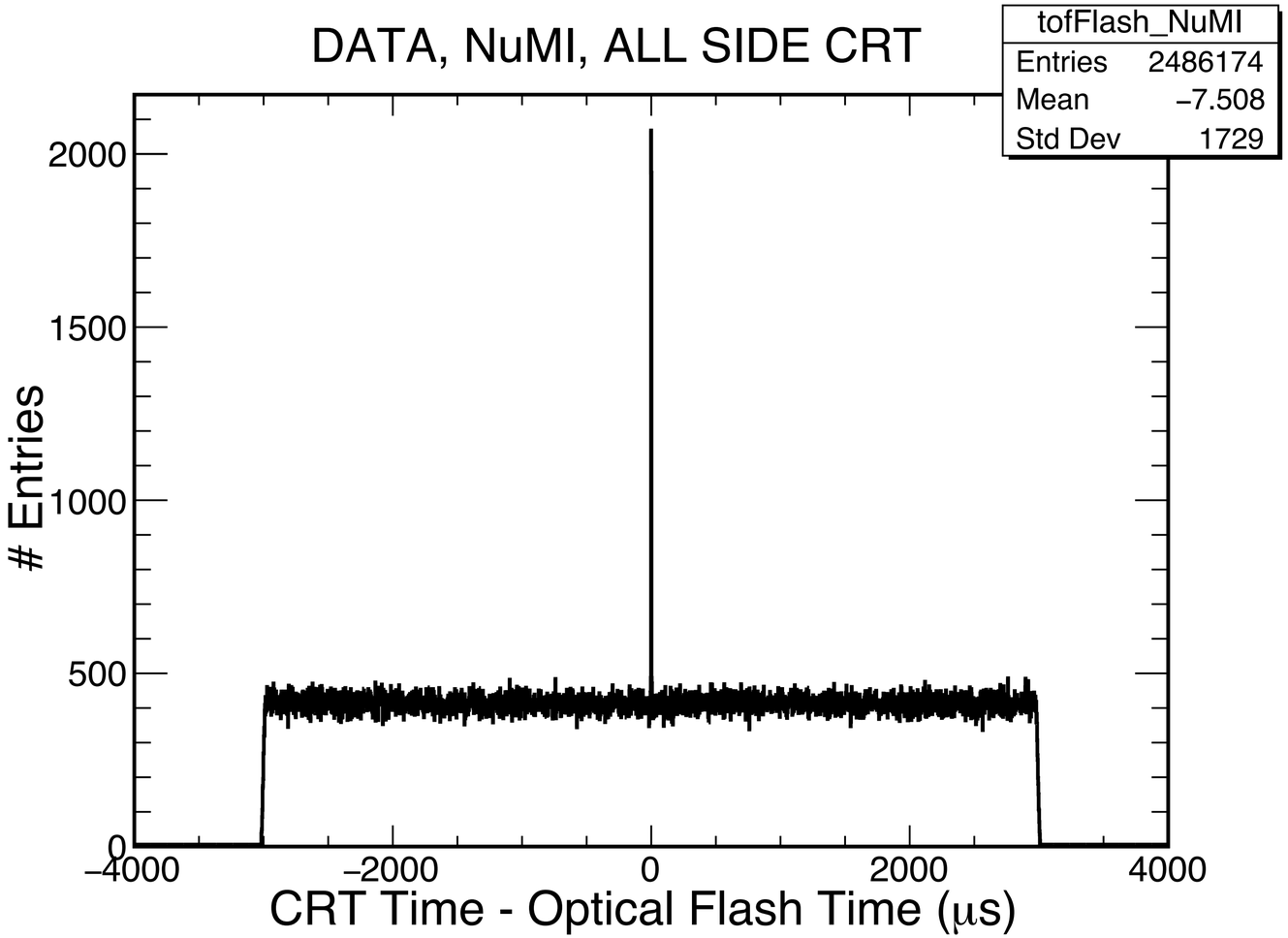
$T_{CRT} - T_{PMT} < 0$ (cosmic track)

Currently exploring good reconstruction of time synchronization

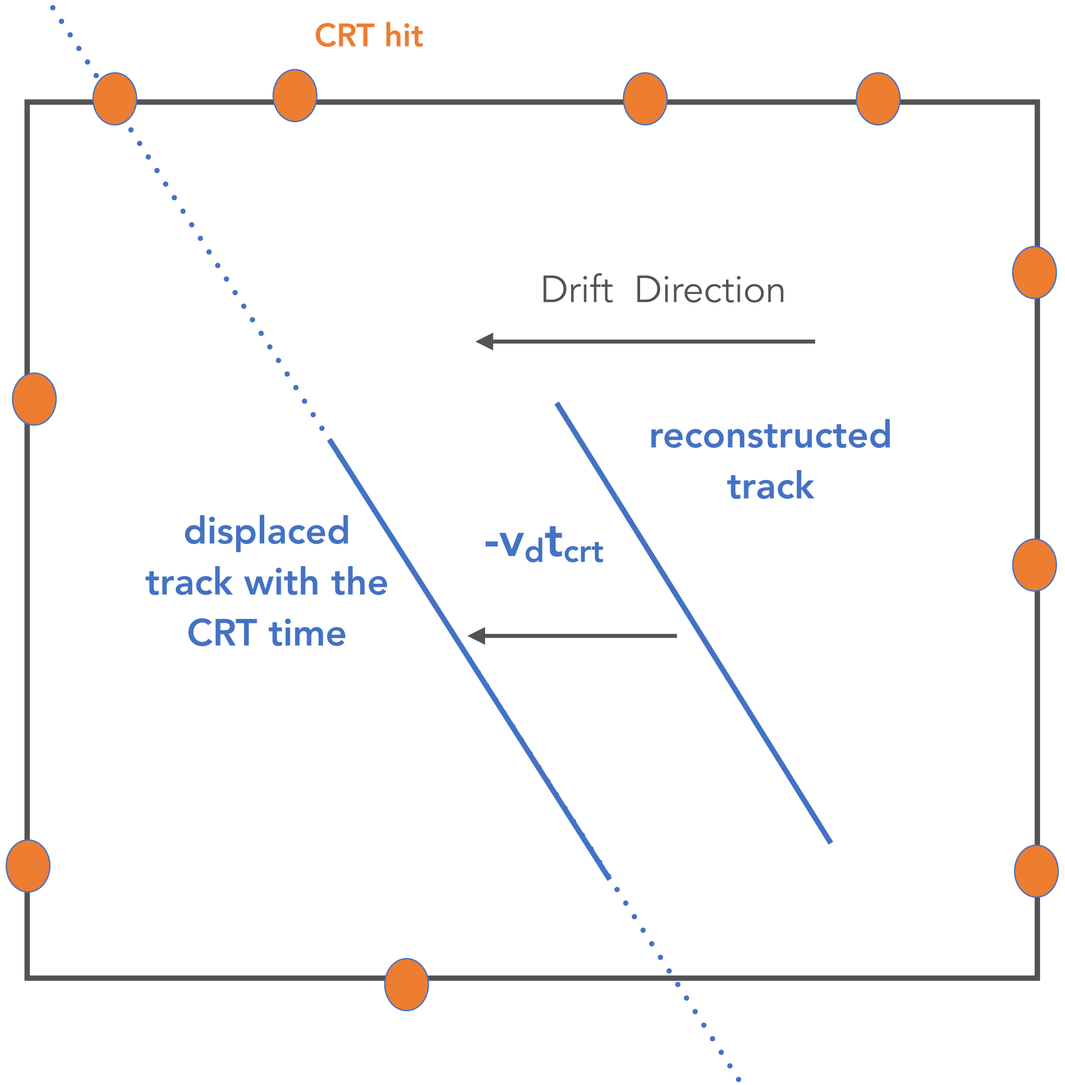
Time of Flight (NuMI, ICARUS DATA)







CRT Hit - TPC Track Association



The track can be wrongly reconstructed since we do not know time from the TPC, but once we drift it according to the time at CRT, we will see a pointing track, then we can say it can not be associated to the trigger.

Algorithm has been tested and looking at data in progress

ICARUS

a

b

Machado PAN, et al. 2019.
Annu. Rev. Nucl. Part. Sci. 69:363–87